

Variations in wood traits in micro and macro propagated plantation woods of *Populus deltoides* Bartr. ex Marsh

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ABSTRACT

The paper presents a comparison between intra-ramet, intra-clonal and inter-clonal variations in girth at breast height (gbh), fiber length, fiber diameter, wall thickness, vessel element length, vessel element diameter and specific gravity in the ramets of L34, G3 and S7C15 clones of *Populus deltoides* at the age of 6 years old produced from planting material grown by macro- and micro-propagation techniques. Variance ratio (F) test indicated that intra-ramet variations were non-significant for all the characters except specific gravity for height in L34 for macro and specific gravity and vessel element diameter for radial locations for micro, and fiber length for G3 (micro) for height, and specific gravity for radial location and fiber length for height for S7C15 clone for both the techniques. The clone L34 showed the significantly higher girth followed by G3 and S7C15. The variations were significant for girth, vessel element length and specific gravity between the wood produced from planting stocks grown by two techniques. Intra-clonal variations were significant for fiber length, fiber diameter and vessel element length. In general wood element's dimensions and specific gravity increased from bottom to top and pith to periphery radial locations. G3 clone was different from the L34 and S7C15 clone for the wood traits. The three different clones of *Populus deltoides* showed variability in wood anatomical properties and specific gravity in the woods grown from macro- and micro-propagated planting stock. So, the plantation raised by two techniques could not produce similar type of wood even from the same clone. G3 clone was the exception as it did not show variation in wood traits for two techniques. Intra-clonal variations in all the three clones of *P. deltoides* indicated that wood traits were not stable within the population of same clone grown by either method.

Keywords: Axial Variation; Radial Variation; Vessel Element's Dimension; Fiber Dimensions; Specific Gravity

1. INTRODUCTION

Populus deltoides is extensively used in plywood, match sticks, sports goods, wood-composites and paper industry. It is grown under different forestry programs as clonal plantations to ensure the genetic superiority for better growth and superior wood quality. Poplar is routinely propagated through shoot cuttings (macro-propagation). But, some plantations were also raised through micro-propagation techniques (tissue culture).

The variability in wood anatomical characteristics has profound influence on the properties of wood [1,2]. Features of interest in this connection include cell size, proportion and arrangements of different elements and specific gravity. The general pattern of variation in wood element dimensions is found not only within a species but also observed within a tree [3-6].

Variations in the dimensions of wood elements and specific gravity both within the ramet and among the clones have come under close scrutiny in recent years. There are reports available on the variation in wood anatomical and other properties in different clones of *Populus* elsewhere [7-10]. It showed that existing literature is only available on the screening of wood quality of poplar clones propagated by macro-propagation technique. No report is available on the comparison of variations on wood properties of macro-propagated with micro-propagated plantation wood.

The growth and wood quality are the two important parameters for the assessment of clones considering their end uses. The parameters viz., wood elements dimensions, specific gravity and growth should be compared for two types of plantation woods viz. macro and micro-propagated, so that superior mass propagation technique can be recommended for commercial plantations for its specific end uses.

The present paper deals with the intra-ramet, intra-clonal and inter-clonal variations in wood anatomical parameters and specific gravity in plantation wood of three clones of *P. deltoides* viz., L34, G3, S7C15 which were produced from the planting stock grown by the macro- and micro-propagation techniques. This efforts was made to compare the wood properties of the wood produced thereof and harvested at 6 years age.

2. MATERIALS AND METHOD

2.1. The Experimental Site

Study site was located at Rudrapur (Udhamsingh Nagar), Uttarakhand, India. It is situated at around 28°N latitude; 78°E longitude and at the altitude of 200 m asl. The annual rainfall was 1200 mm; of which 88% occurs during June-August. The average maximum summer temperature (April-June) was 36.7°C and average minimum temperature (December-February) was 7.5°C (2005-06). The soil of the site was sandy loam.

2.2. Planting Material

The micro-propagated plantlets of L34 and G3 clones maintained in containers (root trainers) were procured from Tata Energy Research Institute, New Delhi (India) during February/March 1996, whereas, that of S7C15 clone were procured from the State Forest Department (Haldwani) which they also reportedly procured from the Tata Energy Research Institute, New Delhi (India) during the same period. The plantlets of these three clones were planted along with the standard shoot cuttings (20-22 cm long with 3-4 alive and sound buds) in the nursery beds at the spacing of 80 cm x 50 cm at Research and Development Complex of Wimco Seedlings Ltd., Bagwala (India) during the month of March 1996. The nursery plants were grown through out the year by adopting standard cultural operations followed in growing poplar nurseries. Entire Transplants (ETPs-common name for the planting stock of poplar) of three clones were grown by using micro- and macro-propagation techniques.

The field trial for comparing the performance of the planting stock originally produced by both the techniques was established in Plot No. 6 of Nurpur Block of Parag Agro Farm Ltd. Kichha, Udham Singh Nagar, Uttarakhand in the Randomised Block Design having four replications. Each replicated plot was having 25 plants planted at 7 m x 3 m spacing over an area of 25 m². The total experimental area was therefore 12600 m² (1.26 ha) having planting stock of three clones grown from micro- and macro-propagated techniques (six treatments) in four replications. The trial was planted in the field on 18th January, 1997. The data on the growth and development of these trees was recorded each year; however

the data during the harvesting of the trees at six years is only presented in this paper to indicate the growth variation in the trees during felling. The final survival of the entire trial was 65.7% in which planting stock of micro-propagated origin gave slightly better survival in all the three clones when compared with that of macro-propagated planting stock. The average tree in term of diameter growth was located in each replicated plot and trees from only three replicates were considered for the study. Height and diameter growth of each average tree from each clone in both macro- and micro-propagated categories considered for the present study are given in **Table 1**.

2.3. Sampling

Three ramets, propagated each from micro- and macro-propagated technique for each clone, were consider for this study. In total 18 ramets were felled during January, 2003 for the study. The height and girth of each tree was recorded. Four transverse discs of 10 cm thickness were cut from the trunk; one each at the base and from different three vertical heights at the 2.5 m regular intervals. In total, 72 discs were collected. The discs were referred as D1, D2, D3 and D4 from the base. Each disc was divided into three peripheral direction *i. e.* north, north-east and south-west to cover the peripheral variations. Each direction was divided into three pith to periphery radial locations *viz.* inner, middle and outer. Besides, a central block (pith) from each disc was also considered to see the variation in pith wood. In total 720 sample blocks were considered for anatomical studies like fiber length, fiber diameter, wall thickness, vessel element length, vessel element diameter and specific gravity. Standard laboratory methods were followed for the preparation of macerations. Wooden chips were fragmented into small pieces and put in the test tube. The material was macerated under 50% HNO₃ and a pinch of KClO₃. The macerated wood elements were thoroughly mixed and were spread on a glass slide and observations were taken under compound microscope [11]. Measurements for fiber length, fiber diameter, wall thickness, and vessel element length and vessel element diameter were taken from the macerated wood. Twenty five unbroken cells were

Table 1. Growth data of selected clones.

Clone	Origin	Average Height (m)		Av Diameter (cm)	
		Macro	Micro	Macro	Micro
L. 34	Lalkuan	28.3 ± 0.37	20.1 ± 0.42	27.9 ± 0.49	18.4 ± 0.85
S7C15	USA	23.3 ± 0.32	19.5 ± 0.64	22 ± 0.21	18 ± 0.19
G3	USA	25.1 ± 0.07	15.3 ± 0	22.9 ± 0.32	12.1 ± 0

sampled for the measurement of each parameter [12]. Specific gravity was determined by using the following formula [11].

$$\text{Basic density} = \text{Oven dry weight}/\text{green volume}$$

The basic density was converted into specific gravity as density of a wood sample relative to the density of water.

2.4. Statistical Analysis

The data obtained were statistically analyzed (using SPSS 10) Multivariate analysis to test the intra-ramet, intra-, inter-clonal variations and variations between the wood produced from planting stock originated by two techniques *i. e.* macro and micro- propagation. The null

hypothesis of ANOVA (M) was there were no variations in selected wood anatomical parameters and specific gravity due to the fixed factors viz. radial location, peripheral direction, height, replication, clone and method of propagation. Finally, Variance ratio (F) test was used for the test of significance. The cluster analysis was done using SPSS 10 for wood anatomical properties and specific gravity.

3. RESULTS

Wood element's dimensions and specific gravity of selected clones of *Populus deltoides* propagated by macro- and micro-propagation techniques and the results of Multivariate analysis are given in **Table 2** to **9**.

Table 2. Pith to periphery variations in wood element's dimensions (μm) and specific gravity in micro and macro propagated wood (I = inner, M = middle, O = outer).

Clone	Location	FL	SD	FD(SD	WT	SD	VL	SD	VD	SD	SG	SD
L34 Macro	I	956.67	76.31	23.67	1.04	3.50	0.15	522.11	32.85	99.3	5.458	0.371	0.030
	M	964.17	98.51	23.64	1.02	3.57	0.23	517.50	28.12	100.2	5.278	0.375	0.023
	O	960.03	63.32	23.89	0.96	3.60	0.37	518.31	35.25	100.9	7.328	0.407	0.049
	Mean	960.29	79.38	23.73	1.01	3.56	0.25	519.31	32.07	100.1	6.021	0.384	0.034
Micro	I	981.50	51.69	21.65	1.38	3.55	0.22	527.75	50.27	89.9	6.349	0.364	0.023
	M	992.39	51.31	21.99	1.43	3.52	0.22	546.36	41.69	91.3	5.469	0.375	0.045
	O	1015.33	94.93	22.10	1.36	3.59	0.25	557.94	43.12	91.6	6.685	0.399	0.041
	Mean	996.41	65.98	21.91	1.39	3.55	0.23	544.02	45.03	90.9	6.168	0.379	0.037
G3 Macro	I	1032.19	78.04	23.31	1.28	3.82	0.43	536.67	45.72	98.1	8.726	0.395	0.031
	M	1086.89	113.45	23.06	1.19	4.54	3.87	544.28	39.20	98.1	9.193	0.420	0.041
	O	1106.33	127.11	23.22	1.20	3.87	0.43	557.17	40.46	101.6	10.327	0.417	0.041
	Mean	1075.14	106.20	23.19	1.23	4.08	1.58	546.04	41.79	99.3	9.415	0.411	0.037
Micro	I	1080.69	134.24	23.72	1.73	3.96	0.47	578.78	32.82	96.2	8.255	0.336	0.025
	M	1083.69	128.52	23.61	1.64	4.03	0.41	577.72	33.31	117.8	136.264	0.334	0.028
	O	1073.11	112.39	23.44	1.78	4.01	0.40	572.75	32.67	95.0	13.624	0.366	0.027
	Mean	1079.17	125.05	23.59	1.72	4.00	0.43	576.42	32.93	103.0	52.714	0.345	0.027
S7C17 Macro	I	1022.03	133.02	22.39	1.25	4.18	0.26	548.92	46.97	90.4	6.005	0.367	0.034
	M	999.17	126.43	22.61	0.99	4.11	0.29	560.56	47.79	92.8	6.193	0.375	0.031
	O	1009.67	129.90	22.64	1.27	4.14	0.35	552.75	47.49	91.9	4.281	0.405	0.032
	Mean	1010.29	129.78	22.55	1.17	4.15	0.30	554.07	47.42	91.7	5.493	0.383	0.032
Micro	I	952.92	46.38	23.44	0.61	3.75	0.14	539.25	17.10	97.3	3.148	0.354	0.024
	M	950.89	46.09	23.42	0.69	3.74	0.13	538.81	24.91	97.3	4.579	0.360	0.030
	O	958.64	50.35	23.47	0.56	3.71	0.13	539.75	15.48	95.8	12.597	0.392	0.038
	Mean	954.15	47.61	23.44	0.62	3.73	0.13	539.27	19.16	96.8	6.775	0.369	0.031

Note: FL = fiber length, FD = fiber diameter, WT = wall thickness, VL = vessel element length, VD = vessel element diameter, SG = specific gravity.

3.1. Variations in Micro vs. Macro Propagated Wood

3.1.1. Variations for All Clones

3.1.1.1. Variation in Growth

Variance ratio (F) test indicated that variation in girth at breast height (gbh) was significant for clone, technique and height. The clone L34 showed the significantly higher girth followed by G3 and S7C15 clone. The girth (cm) was significantly higher in macro-propagated than micro-propagated ramets (**Table 6**). The girth significantly varied from bottom to top. The average girth (cm) of 3 clones at selected height was in D1 (77.39), D2 (61), D3 (55.78) and D4 (46.72).

3.1.1.2. Variation in Wood Anatomical Parameters and Specific Gravity

Variance ratio (F) test indicated that intra-ramet variations were non-significant for all the characters except specific gravity for height in L34 for macro and specific gravity and vessel element diameter for radial locations for micro, and fiber length for G3 (micro) for height, and specific gravity for location and fiber length for height in S7C15 clone for both the techniques (**Table 5**) while inter-clonal variations were significant for fiber length, fiber diameter, wall thickness and vessel element length. The variations were significant for techniques (micro and macro-propagated) for vessel element length and specific gravity. Intra-clonal variations were significant for fiber length, fiber diameter and vessel element length (**Table 6**). In general wood element's dimensions and specific gravity increased from bottom to top and pith to periphery locations (**Table 2** and **3**). The average values of all the clones indicated that wall thickness and specific gravity were higher in macro-propagated wood while fiber length and vessel element length in micro-propagated wood. The range was 954 μm (S7C15, micro)-1079 μm (G3, micro) for fiber length; 21.91 μm (L34, micro)-23.73 μm (L-34, macro) for fiber diameter; 3.55 μm ((L34, micro)-4.15 μm (S7C15, macro) for wall thickness; 519 μm (L-(L34, macro) – 575 μm (G3, micro) for vessel element length; 92 μm (S7C15, macro) – 103 μm (G3, micro) and 0.345 (G3, micro)-0.411 (G3, macro) (**Table 5**). The grouping of different clones for fiber length was (S7C15-micro, L34-macro), (L34-micro, L34-macro), (L34-micro, S7C15-macro), (G3-macro, G3-micro); for fiber diameter was (L34-micro), (S7C15-macro), (G3-macro, S7C15-micro, L34-macro) for wall thickness was (L34-micro, L-34 macro, S7C15-micro), (G3-micro, G3-macro, S7C15-macro); for vessel element length was (L34-macro), (G3-macro), (S7C15-micro, L34-micro, G3-macro, S7C15-macro) and for specific gravity was (G3-micro), (S7C15-micro,

L34-micro, S7C15-macro), (L34-macro, S7C15-macro, L34-macro) and (G3-micro). The percent co-variance indicated that there was not much difference between variation pattern of micro and macro propagated plantation wood (**Table 4**).

3.1.2. Variations in Individual Clones

3.1.2.1. L-34 Clone

Variations in wood element's dimensions between micro and macro propagated plantation's wood were significant for fiber length, fiber diameter, vessel element length and vessel element diameter; fiber length, fiber diameter, wall thickness and vessel element diameter for replication; vessel element diameter for bottom to top; fiber length for peripheral direction and specific gravity for radial locations. Fiber length and vessel element length were significantly higher in micro-propagated wood while fiber diameter and vessel element diameter were significantly higher in macro-propagated wood (**Table 7**). Bottom to top variation for fiber length ranged between 935 μm (D3) to 985 μm and specific gravity ranged between 0.367 (D1) to 0.392 μm (**Table 3**).

3.1.2.2. G3 Clone

Variations between micro- and macro-propagated plantation's wood were significant for vessel element length and specific gravity; fiber length, fiber diameter and vessel element length for replication; vessel element length and specific gravity for bottom to top and specific gravity for radial locations. Vessel element length was significantly higher for micro-propagated wood while specific gravity for macro- propagated wood (**Table 8**). Bottom to top variation for fiber length ranged between 1053.67 μm (D2)-1122.41 μm (D1) (**Table 3**).

3.1.2.3. S7 C15 Clone

Fiber length, fiber diameter, wall thickness and vessel element length significantly varied between micro- and macro-propagated plantation's wood; fiber length, wall thickness, vessel element length and specific gravity for replication; fiber length for bottom to top and specific gravity for radial locations. Fiber length, wall thickness and vessel element length was significantly higher in macro-propagated wood whereas fiber diameter in micro propagated wood (**Table 4** and **9**). Bottom to top variation for fiber length ranged between 958 μm (D3) to 1053.37 μm (D1).

3.2 Variations in Macro Propagated Wood

3.2.1 Variations in All Clones

Variations in all wood elements' dimensions were significant for clones; fiber length, fiber diameter, vessel element length and specific gravity for replication; fiber length and specific gravity for bottom to top and for radial

Table 3. Bottom to top variations in wood element's dimensions (μm) and specific gravity (D1 bottom disc and D2, D3, and D4 are 4 successive discs at the 2.5 m intervals).

Parameter/Clone		Macro						Micro							
		FL	FD	WT	VL	VD	SG	FL	FD	WT	VL	VD	SG		
L 34	D 1	Mean	973.52	23.56	3.47	514.04	100.56	0.38	981.67	21.56	3.63	531.30	91.15	0.367	
		SD	73.26	0.91	0.18	29.83	3.38	0.04	63.82	1.55	0.21	36.03	3.12	0.028	
	D2	Mean	946.63	24.11	3.53	517.11	101.74	0.38	1011.44	21.67	3.52	550.67	93.52	0.375	
		SD	58.16	1.22	0.22	32.77	4.09	0.03	101.44	1.42	0.29	44.62	7.77	0.030	
	D3	Mean	935.37	23.84	3.61	524.37	100.33	0.38	1002.70	22.09	3.53	549.67	88.07	0.383	
		SD	49.58	0.58	0.37	30.93	8.78	0.04	56.51	1.50	0.19	65.32	6.76	0.030	
	D4	Mean	985.63	23.43	3.61	521.70	97.78	0.39	989.81	22.32	3.53	544.44	91	0.392	
		SD	115.94	1.09	0.26	34.93	6.15	0.05	44.67	0.94	0.20	32.94	5.061	0.061	
	Mean		960.29	23.73	3.56	519.31	100.10	0.38	996.41	21.91	3.55	544.02	90.935	0.379	
	SD		74.24	0.95	0.25	32.11	5.60	0.04	66.61	1.35	0.22	44.73	5.679	0.037	
	G3	D1	Mean	1063.89	23.41	3.74	557.93	103.30	0.38	1103.22	23.26	4.14	589.59	101.481	0.326
			SD	107.92	1.45	0.44	39.29	13.07	0.03	156.96	0.86	0.28	31.91	18.404	0.020
D2		Mean	1053.67	23.22	3.94	552.67	97.89	0.40	1110.37	23.33	4.2	574.78	95.667	0.359	
		SD	82.43	1.15	0.19	34.10	6.13	0.04	139.04	1.14	0.29	39.64	5.657	0.025	
D3		Mean	1060.59	22.81	4.76	527.07	96.41	0.43	1056.85	24.04	3.82	572.48	92.481	0.352	
		SD	122.33	1.27	4.46	47.39	9.89	0.04	101.23	2.46	0.61	30.20	6.435	0.033	
D4		Mean	1122.41	23.33	3.87	546.48	99.41	0.43	1046.22	23.74	3.85	568.81	122.296	0.345	
		SD	121.69	0.92	0.61	43.19	6.15	0.03	78.15	1.87	0.31	25.46	157.546	0.032	
Mean			1075.14	23.19	4.08	546.04	99.25	0.41	1079.17	23.59	4.00	576.42	102.981	0.345	
SD			108.59	1.20	1.43	40.99	8.81	0.03	118.85	1.58	0.37	31.80	47.011	0.028	
S7C15		D1	Mean	1053.37	22.44	4.11	545.33	89.41	0.37	962.67	23.33	3.66	532.59	96.519	0.355
			SD	171.31	1.09	0.37	46.65	6.46	0.04	32.41	0.68	0.12	11.28	4.173	0.031
	D2	Mean	1052.37	22.70	4.16	549.11	91.30	0.39	967.44	23.44	3.71	534.78	97.963	0.366	
		SD	159.98	1.35	0.32	59.90	7.16	0.04	49.20	0.51	0.11	23.40	3.436	0.033	
	D3	Mean	958.63	22.30	4.09	550.33	92.04	0.38	969.07	23.44	3.76	548.22	99.222	0.380	
		SD	65.84	1.27	0.23	33.61	3.09	0.03	52.45	0.75	0.12	21.25	4.003	0.037	
	D4	Mean	976.78	22.74	4.21	571.52	93.96	0.39	917.41	23.56	3.80	541.48	93.481	0.374	
		SD	37.87	0.94	0.26	43.01	3.92	0.04	33.14	0.51	0.14	16.43	13.891	0.036	
	Mean		1010.29	22.55	4.15	554.07	91.68	0.38	954.15	23.44	3.73	539.27	96.796	0.369	
	SD		108.75	1.16	0.30	45.79	5.16	0.04	41.80	0.61	0.123014	18.09	6.376	0.034	

Note: FL = fiber length, FD = fiber diameter, WT = wall thickness, VL = vessel element length, VD = vessel element diameter, SG = specific gravity.

Table 4. Mean \pm SD for wood element's dimensions (μm) and specific gravity.

Parameter/Clone	FL	FD	WT	VL	VD	SG	
L34	Mean	960	24	3.56	519	100	0.384
	Macro SD	80	1	0.27	32.0	6.1	0.039
	%CV	8	4	8	6	6	10
	Mean	996	22	3.55	544	91	0.379
	Micro SD	70	1	0.23	46	6	0.040
	%CV	7	6	6	9	7	11
G3	Mean	1075	23	4.08	546	99	0.411
	Macro SD	112	1	2.27	42	9	0.039
	%CV	10	5	56	8	10	9
	Mean	1079	24	4.00	576	103	0.345
	Micro SD	124	2	0.42	33	11	0.030
	%CV	12	7	11	6	11	9
S7C15	Mean	1010	23	4.15	554	92	0.383
	Macro SD	129	1	0.30	47	6	0.036
	%CV	13	5	7	9	6	9
	Mean	954	23	3.73	539	97	0.369
	Micro SD	47	1	0.13	19	8	0.035
	%CV	5	3	4	4	8	10

Note: FL = fiber length, FD = fiber diameter, WT = wall thickness, VL = vessel element length, VD = vessel element diameter, SG = specific gravity, SD = standard deviation, CV = covariance.

direction (Table 6). The range was 960 μm (L34) – 1075 μm (G3) for fiber length; 22.55 μm (S7C15) – 23.73 μm (L34) for fiber diameter; 3.56 μm (L34) – 4.15 μm (S7C15) for wall thickness; 519 μm (L34) – 554 μm (S7C15) for vessel element length; 91.68 μm (S7C15) – 100.10 μm (L34) for vessel element diameter and 0.38 (S7C15) – 0.41 (G3) for specific gravity. The percent variations were recorded for 8 (L34) – 13 (S7C15) for fiber length; 7 (S7C15) – 56 (G3) for wall thickness; 6 (L34) – 9 (S7C15) for vessel element length and 6 (L34) – 10 (S7C15) for vessel element diameter (Table 4). It showed that clones and replicate ramets showed variations in the wood element dimensions and specific gravity.

3.2.2 Variations in Individual Clones

3.2.2.1. L-34 Clone

Variations were significant for fiber length, wall thickness and vessel element length for replication; fiber

length for bottom to top and specific gravity for radial locations (Table 7). The pith to periphery variations were ranged between 957 μm (pith) – 964 μm (middle) for fiber length; 23.64 μm (middle) – 23.89 μm (outer) for fiber diameter; 3.50 μm (pith) – 3.60 μm (outer) for wall thickness and 0.371 (pith) – 0.407 (outer) for specific gravity.

3.2.2.2. G3 Clone

Variations were significant for fiber length, fiber diameter, vessel element length, vessel element diameter and specific gravity for replication; fiber length and specific gravity from bottom to top and fiber length and specific gravity for radial locations (Table 8). The pith to periphery variations were ranged between 1032 μm (pith) – 1106 μm (outer) for fiber length and 0.395 (pith) – 0.42 (middle) for specific gravity (Table 2).

3.2.2.3. S7 C15 Clone

Variations were significant for all the characters except vessel element diameter for replication; fiber length for bottom to top and specific gravity for radial locations (Table 9). The pith to periphery variations were ranged between 0.367 (pith) – 0.405 for specific gravity (outer) (Table 2).

3.3. Variations in Micro Propagated Wood

3.3.1. Variations in All Clones

Fiber length, fiber diameter, wall thickness, vessel element length and specific gravity significantly varied for clones; fiber length, fiber diameter and vessel element length for replication; fiber length and specific gravity for bottom to top; fiber length and specific gravity for peripheral direction and specific gravity for radial locations in micro propagated trees (Table 6). The range was 954 μm (S7C15) – 1079 μm (G3) for fiber length; 21.91 μm (G3) – 23.59 μm (G3) for fiber diameter; 3.55 μm (L34) – 4.0 μm (G3) for wall thickness; 539 μm (S7C15) – 546 μm (G3) for vessel element length; 90.94 μm (L34) – 102.98 μm (G3) for vessel element diameter and 0.35 (G3) – 0.379 (L34) for specific gravity. The percent variations were recorded for 5 (S7C15) – 12 (G3) for fiber length; 4 (S7C15) – 11 (G3) for wall thickness; 4 (S7C15) – 9 (L34); 6 (L34) – 11 (G3) for vessel element length (Table 4). It shows that variations in wood element dimensions have not much difference among different clones.

3.3.2. Variations in Individual Clones

3.3.2.1. L-34 Clone

Variations were significant for fiber length and vessel element diameter for replication; vessel element diameter for bottom to top; fiber length for peripheral direction and specific gravity for radial locations (Table 7). The

Table 5. Intra-ramet variations in different clones.

Wood parameters/Source of variation		MSS					
		FL	FD	WT	VL	VD	SG
L34 (Macro)		df					
Height	3	2164.9	.674	0.023	1359.	49.43	0.019*
Direction	2	70.194	.399	0.026	939.194	22.861	0.0027
Location	2	569.7	0.49	0.011	2531.028	42.52	0.013
Error	28	732.7	.821	0.022	440.7	47.63	0.0011
Micro							
Height	3	20288.102	4.472	0.0037	12200.2	313.963*	0.00073
Direction	2	10802.7	.778	0.0044	5909.361	121.194	0.00028
Location	2	13268.528	1.194	0.017	13022.528	75.444	0.0073*
Error	28	4856.627	1.748	0.056	3297.9	28.835	0.0005
G3 (Macro)							
Height	3	1939.282	1.010	0.01	225.896	15.136	0.004
Direction	2	1073.740	.201	0.036	3052.917	81.419	0.0005
Location	2	2040.307	0.034	0.016	135.816	11.857	0.0045
Error	28	1414.5	.624	0.018	1053.674	16.717	0.0015
Micro							
Height	3	3607.9*	.546	0.026	2924.667	4.963	0.0013
Direction	2	201.083	0.028	0.007	330.333	13.000	0.0016
Location	2	172.583	.361	0.014	193.750	21.000	0.0029
Error	28	364.9	.329	0.021	811.637	10.040	0.00065
S7C15 (Macro)							
Height	3	282340.76*	3.630	.253	2262.7	46.222	0.0027
Direction	2	11651.083	.194	0.019	1954.694	17.028	0.00051
Location	2	6129.250	.778	0.025	3497.861	104.111	0.0066*
Error	28	4930.635	1.312	0.038	2212.048	51.069	0.001
Micro							
Height	3	9797.407*	.324	0.05	1324.917	15.435	0.00085
Direction	2	2315.444	.361	0.0036	839.250	29.694	0.00022
Location	2	920.111	0.028	0.00028	59.250	6.194	0.013*
Error	28	1137.889	.377	0.011	282.393	14.984	0.00010

*P < 0.001. Note: FL = fiber length, FD = fiber diameter, WT = wall thickness, VL = vessel element length, VD = vessel element diameter, SG = specific gravity.

Table 6. ANOVA for wood element's dimensions and specific gravity in macro and micro propagated wood.

Wood parameter/Source of variation	df	MSS						
		FL	FD	WT	VL	VD	SG	gbh
Macro vs micro	df							
Clone	2	676447.0*	17.2*	14.1*	47203.9*	2890.9	0.0019	3862.3*
Technique	1	4602.7	3.99	4.3	29214.8*	1.8	0.126*	3784.5*
Replication	2	445736.2*	58.5*	0.463	15763.9*	316.9	0.0034	29.2
Height	3	27393.7	1.4	0.565	529.6	674.5*	0.019	2983.8*
Direction	2	12263.9	0.344	1.40	3238.25	950.67	0.0019	
Location	2	14159.8	0.628	0.922	3231.35	1148.6	0.064*	
Error	740	8542.8	1.69	0.93	1488.9	1099.5	0.0012	79.7
Macro								
Clone	2	358140.8*	38.1*	11.23*	35784.3*	2323.6*	0.026*	
Replication	2	251225.5*	22.54*	0.920	37336.0*	230.5	0.012*	
Height	3	35733.2	1.76	2.11	2182.41	30.20	0.012*	
Direction	2	4675.1	0.017	3.047	2089.4	27.0	0.00036	
Location	2	12912.2	0.70	1.79	1340.7	134.45	0.023*	
Error	312	10109.9	1.16	1.76	1448.46	51.53	0.00112	
Micro								
Clone	2	436762.3*	93.77*	5.47*	44139.37*	3919.0	0.032*	
Replication	2	268891.7*	45.75*	0.081	5884.08	635.6	0.006	
Height	3	29046.5*	5.212	0.255	532.2	1178.4	0.0085*	
Direction	2	10308.5	0.753	0.085	4454.5	2138.0	0.0058*	
Location	2	3134.7	0.162	0.012	1916.64	2206.15	0.037*	
Error	312	5651.8	1.44	0.082	1153.64	2140.64	0.00093	

*P < 0.001. Note: FL = fiber length, FD = fiber diameter, WT = wall thickness, VL = vessel element length, VD = vessel element diameter, SG = specific gravity.

pith to periphery variations were ranged between 0.364 (pith) – 0.399 for specific gravity (outer) (Table 2).

3.3.2.2. G3 Clone

Fiber length, fiber diameter and vessel element length were significantly varied in replication; fiber length, wall thickness and specific gravity from bottom to top and specific gravity in radial locations (Table 8). The pith to periphery variations were ranged between 0.336 (pith) – 0.366 for specific gravity (outer) (Table 2).

3.3.2.3. S7 C15 Clone

Variations were significant only for fiber length for replications; fiber length, wall thickness and vessel element

length for bottom to top; vessel length for radial direction and specific gravity for radial location (Table 9). The pith to periphery variations were ranged between 0.354 (pith) – 0.392 for specific gravity (outer).

3.4. Cluster Analysis

Hierarchical cluster analysis was done using 'Squared Euclidean Distance' for the three clones grown by two techniques. Dendrogram using average linkage (between groups) was made for different clones considering all studied wood traits (Figure 1). G3 clone was divergent with other clones. L34 (micro) and S7C15 (macro) was different from L34 (macro) and S7C15 (micro) at 6

Table 7. ANOVA for wood element's dimensions and specific gravity in macro and micro propagated wood of L34 clone.

Wood parameters/Source of variation		MSS					
		FL	FD	WT	VL	VD	SG
Macro vs micro	df						
Technique	1	70452.8*	168.6*	0.00012	32979.4*	4537.5*	0.0012
Replication	2	66248.3*	18.6*	0.883*	4642.3	259.1*	0.00003
Height	3	3161.1	0.89	0.027	2098.1	136.3*	0.003
Direction	2	27175.2*	3.26	0.17	3639.2	94.02	0.001
Location	2	6225.7	2.09	0.094	3137.57	52.78	0.026*
Error	205	4870.94	1.32	0.053	1518.6	33.20	0.0013
Macro							
Replication	2	152521.40*	3.90	1.150*	18649.08*	151.60	0.0021
Height	3	14622.160*	2.50	0.126	575.80	75.12	0.00092
Direction	2	7847.07	1.70	0.186	672.30	16.50	0.00053
Location	2	508.07	0.700	0.083	218.40	24.30	0.014*
Error	98	3256.80	.90*	0.045	700.00	34.04	0.0013
Micro							
Replication	2	8878.0	28.89*	0.183	1638.40	464.06*	0.0017
Height	3	4738.60	3.50	0.075	2143.22	134.20*	0.0030
Direction	2	21377.30*	1.444	0.0212	7611.70	108.60	0.0045
Location	2	10738.30	2.00	0.045	8353.50	29.40	0.012
Error	98	4350.4	1.345	0.050*	1933.01	25.245	0.0013

*P < 0.001. Note: FL = fiber length, FD = fiber diameter, WT = wall thickness, VL = vessel element length, VD = vessel element diameter, SG = specific gravity.

rescaled distance cluster combine. The wood properties of G3 clone were similar in the wood produced by two different techniques, whereas the L34 and S7C15 produced wood by two techniques showed variations in wood properties. It showed that G3 clone was stable whereas L34 and S7C15 showed variations in wood traits between the wood produced by two techniques.

4. DISCUSSION

Variance ratio (F) test indicated that inter-clonal variations were non significant for all studied wood traits except wall thickness and fiber length for central block (P < 0.001). Significant inter-clonal variations in wall thickness and vessel element length indicated that these traits had strong inheritance even at the early phase of the tree growth. The pooled data analysis of three clones indicated that fiber length, vessel element length and

specific gravity were the wood traits which varied between macro- and micro-propagated wood of *Populus deltoides* clones (Table 6). Specific gravity and wall thickness were higher in macro-propagated wood while vessel element length in micro-propagated wood. The trend was more or less similar to individual clones. The grouping of different clones indicated that clones behave differently for different wood traits.

Significant inter-clonal variations were reported for fiber length, fiber diameter, fiber wall thickness, vessel element length and specific gravity. Significant differences among the different clonal ramets of different species in average fiber-length are also reported by many workers [7,9,10,13,14]. Cheng and Benseid [15], Einspahar *et al.* [16], Kennedy [17] and Peszlen [18] reported that fiber length is under genetic control. Clone to clone variations were also reported in *Tectona grandis*

Table 8. ANOVA for wood element's dimensions and specific gravity in macro and micro propagated wood of G3 clone.

Wood parameter/Source of variation	df	MSS					
		FL	FD	WT	VL	VD	SG
Macro vs micro	df						
Technique	1	876.04	8.560	.308	49837.80*	751.90	0.230*
Replication	2	790333.80*	84.60*	1.315	222478.70*	1959.40	0.0030
Height	3	8201.70*	0.70*	1.9	5529.20	2875.30	0.016*
Direction	2	9263.04	0.50	2.80	28.10	2520.06	0.000093
Location	2	23510.40	0.80	3.24	945.30	2522.70	0.012*
Error	205	6428.21	1.4	2.70	1185.9	3208	0.0009
Macro							
Replication	2	238056.80*	28.90*	4.54	15315.60*	702.90*	0.0072*
Height	3	27301.70*	1.90	5.8	4905.80	237	0.015*
Direction	2	6631.0*	.111	6.80	795.90	72.30	0.00005
Location	2	53196.90*	.60	5.80	3865.8	150.50	0.0066*
Error	63	6712.60	.96	5.09	1401.06	72.40	0.00092
Micro							
Replication	2	601137.7*	61.80*	.50*	9300.25	3811.40	0.00082
Height	3	28220.70*	3.60	1.03*	2246.08	4851.60	0.0056*
Direction	2	8056.08	1.0	.30	490.50	6263.20	0.0004
Location	2	1071.08	0.704	0.039	373.03	5923.40	0.011*
Error	63	3676.60	1.7	.15	865.0	6411.20	0.00059

*P < 0.001. Note: FL = fiber length, FD = fiber diameter, WT = wall thickness, VL = vessel element length, VD = vessel element diameter, SG = specific gravity.

for wood properties [19], in *D. sissoo* by Pande and Singh [20] and in *Populus deltoides* by Chauhan *et al.* [10]. Further, Veenin *et al.* [21] reported significant inter-clonal variation in wood anatomical properties and specific gravity in *Eucalyptus camaldulensis*. In the present study clone to clone variation in specific gravity was observed. Significant inter-clonal variations in specific gravity of *Eucalyptus tereticornis* at the one site was reported by Pande [22]. Significant differences in average specific gravity of different clones in the present study are also in agreement with the earlier findings in *Populus* spp. [7,9], in *Eucalyptus tereticornis*. [14] and in *Dalbergia sissoo* [20,23]. Specific gravity is moderately to strongly inherited trait and is under the influence of additive gene action in case of *Tectona grandis* [24].

Non-significant intra-clonal variations were reported

by Pande and Singh [20] in *D. sissoo* and in *E. tereticornis* by Pande [22]. In contrary, present study showed significant intra-clonal variation in fiber length, fiber diameter, wall thickness, vessel element length and specific gravity in macro; fiber length, and fiber diameter and vessel element length in micro propagated plantation wood. It showed that with in clone variability is present among the clonal ramets of *Populus deltoides*. It showed that intra-clonal variations for different wood traits are varied differently for different species and clones.

Axial and horizontal (both peripheral and radial) in pooled data of all the clones were non-significant except specific gravity. But, the individual clone with micro- or macro-propagated method showed somewhat different trend. It showed non-significant variations in most of the cases except few sporadic exceptions. L34 clone showed axial variation for specific gravity in macro-propagated

Table 9. ANOVA for wood element's dimensions and specific gravity in macro and micro propagated wood of S7C15 clone.

Wood parameter/Source of variation		MSS					
		FL	FD	WT	VL	VD	SG
Macro vs micro	df						
Technique	1	170185.04*	43.56*	9.16*	11837.04*	1415.78	0.01
Replication	2	257777.42*	3.81	0.53*	11688.91*	60.67	0.008*
Height	3	54062.63*	1.02	0.14	3332.86	71.67	0.005*
Direction	2	6310.37	1.45	0.0003	21478.1	214.3	0.0001
Location	2	2989.78	0.37	0.03	573.51	36.29	0.02*
Error	205	6448.84	0.85	0.04	1178.12	46.85	0.0008
Macro							
Replication	2	327993.70*	12.30*	1.50*	27288.9*	132.23	0.011*
Height	3	66766.80*	1.22	0.083	3774.0	95.90	0.0027
Direction	2	2463.60	2.01	0.0056	1254.0	2.90	0.00083
Location	2	4714.07	0.70	0.044	1266.50	53.80	0.014*
Error	63	9267.01	1.20	0.064	1711.30	27.40	0.0008
Micro							
Replication	2	41614.80	0.75	0.053	151.70	1.12	0.0006*
Height	3	16398.2*	0.22	0.098*	1348.2*	164.80	0.0031
Direction	2	4518.40	0.36	0.0025	2088.8*	13.62	0.0025
Location	2	581.50	0.027	0.010	8.04	26.60	0.014*
Error	63	989.00	0.40	0.014	324.50	62.40	0.00089

*P < 0.001. Note: FL = fiber length, FD = fiber diameter, WT = wall thickness, VL = vessel element length, VD = vessel element diameter, SG = specific gravity.

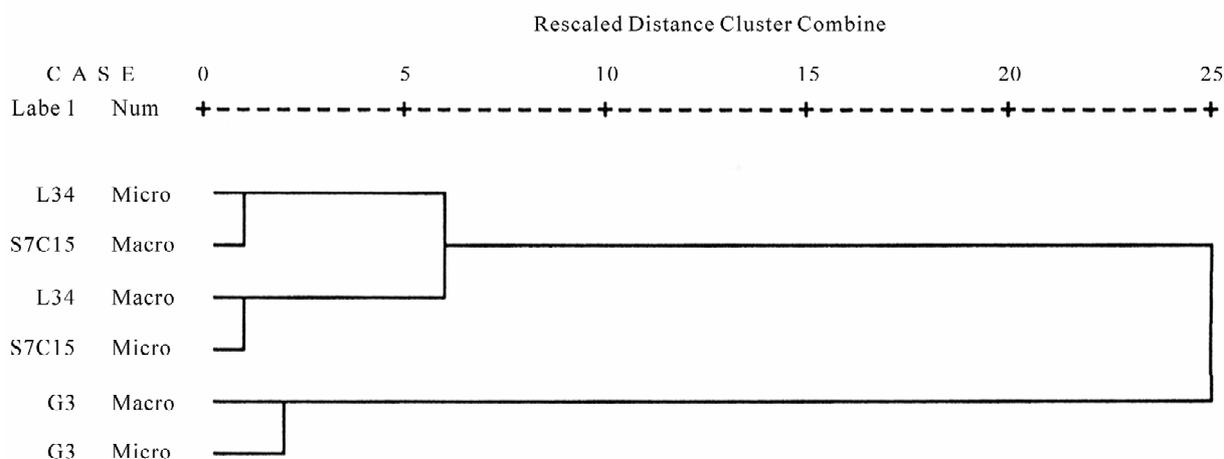


Figure 1. Dendrogram using the wood parameters for three clones with both macro and micro-propagation method.

wood while for micro-propagated wood variations were for vessel element diameter and specific gravity. In G3 and S7C15 clone, axial variations were represented only for fiber length. Radial variation was only for specific gravity for all the clones. It showed that clones of *Populus deltoides* presented different patterns of within tree variations for different wood traits. Even the pattern was not same for individual clone grown by two different techniques. Significant radial variations for fiber length in some poplar clones were also recorded by Kaubaa *et al.* [8]; and in vessel lumen diameter and fiber length by Peszlen, [18]. In general, non-significant variations due to peripheral direction and radial location in wood element dimensions within a ramet and absence of any trend may be related to the early maturity of clone-raised tree. It appears that growing age may not have any impact on the wood element dimensions in clonal ramets of *Populus deltoides* even at the early phase of tree growth. Veenin *et al.* [21] also reported non-significant radial variations in fiber length, vessel element diameter and vessel density in clone raised ramets of *E. camaldulensis*. Such type of results were also reported in clonal plantation of *Populus deltoides* by Chauhan *et al.* [10]; *Dalbergia sissoo* by Pande and Singh [20] and in *Eucalyptus tereticornis* by Pande [22]. However, within tree axial and horizontal variations in wood element's dimension in seed raised trees of different species were reported [6,11,14,25,26]. In general, the increasing trend for specific gravity was observed from bottom to top and pith to periphery. However, radial variations in specific gravity in *E. camaldulensis* are reported by Veenin *et al.* [21]. In *Tectona grandis*, the density increased towards the peripheral direction by 5-6 cm from the pith which stabilizes by the age of 10-12 years [27]. In the case of *Dalbergia sissoo* and other clones of *Populus deltoides*, there was non-significant pith to periphery radial variations and no specific trend was observed for specific gravity [10,20]. Thus, the trends can be different from one species to another.

5. CONCLUSIONS

Populus deltoides clones showed differential pattern of variability for different wood traits. The three different clones of *Populus deltoides* showed variability in wood anatomical properties in the woods of micro- and macro-propagated plantation. So, the plantation raised by two techniques could not produced similar type of wood even from the same clone. G3 clone was the exception as it did not show variations in wood traits for two techniques.

In general, the higher specific gravity and fiber wall thickness can be obtained by growing the plantation of this species by macro-propagation techniques.

Variations are observed in fiber dimensions in macro-propagated wood of all three clones. G3 clone is stable for wood traits as it showed similar type of wood properties in the wood grown by the two techniques. Further, it showed higher fiber dimensions and specific gravity than of the other clones.

Intra-clonal variations in all the three clones of *Populus deltoides* indicated that wood traits were not stable within the population of same clone grown by either method.

Non-significant intra-ramet variation in wood anatomical characteristics in both the techniques indicated narrow juvenile wood zone and may form mature wood even at the early phase of tree growth.

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